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Laser propagation in underdense plasmas

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Propagation of an intense laser pulse in an underdense plasma is modelled by treating the electrons as a cold relativistic fluid. For sufficiently short pulses, the ion motion is negligible. The disparities between the optical, plasma, and propagation length scales are dealt with by using a multiple scales technique to derive approximate equations averaged over successively larger length scales. This argument does not require the quasistatic approximation (QSA) often used in earlier work, and it shows that, in the coordinate system moving with the pulse, the fluid will exhibit transient (initial layer) behavior in time. Asymptotically, i.e., for times long on the plasma scale, the transient solution approaches the QSA. The problem of matching the transient (inner) solution to the asymptotic (outer) solution is solved by means of a uniformly valid, two-time expansion. The QSA is shown to suffer from instabilities which could cause serious problems for numerical simulations of long pulses, and an "improved-QSA", suggested by the inner-outer analysis, is demonstrated. An analytical solution for a planar, weak-field model is presented which explicitly displays the initial layer behavior of the fluid. For a short, cylindrically symmetric, weak-field pulse numerical simulations which include relativistic self focusing, forward Raman scattering, and ponderomotive forces show the importance of the transient effects in a more realistic case.

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